A THREE-DIMENSIONAL MODEL OF THE MANDIBLE USING TWO-DIMENSIONAL CT IMAGES

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Abstract-**In dentistry, instead of conventional prosthetic applications, dental implant prosthesis has recently been used in edentate patients. Biomechanical effects are known to be one of the most important factors in the failure of these implants.**

In this work, a three-dimensional model of the edentate mandible is formed to use in three-dimensional finite element method for the stress analysis of chewing forces. The computerized three-dimensional solid geometric mandible model is formed by using commercially available CAD tools on a series of two-dimensional CT images obtained from a Hi-speed CT/I imaging system. Satisfactory results on several implant schemes on this model are obtained by applying various critical chewing forces.

***Keywords* - Three-dimensional finite element model, CT images, mandible**

I. INTRODUCTION

Nowadays, the aim of modern dentistry is to supply normal oral contour, function, esthetics, and comfort without considering the atrophy, injury or diseases of the stomatognatic system. Oral implantology is one of the most developing disciplines of modern dentistry and needs progressive studies.

In dentistry, the first finite element (FE) analysis is the study of the stress distribution of central forces on silver amalgam fillings made by Noonan. In 1954 Haskins, Haack, and Ireland, in 1955 Mahler and Peyton, and in 1962 Lehman and Hampson used this method in dentistry for creating the mathematical tooth models. In 1973, the first finite element analysis on dental implants was done by Tesk and Widera [1].

One-, two- or three-dimensional (3-D) analysis of a structure can be made in an elasticity problem solved by this method. By using this method, structures in different shapes can be modelled and divided into simpler geometrical figures or elements combining each other on node points [1]. Because of the ease of its application, two-dimensional (2-D) FE analysis has been used in many studies in dentistry. However, two-dimensional analysis leads to inaccurate results.

For the reason that the structure can be modelled by volume, studies on stress distribution of different dental restoration materials, various dental implant materials and systems, and also orthopaedic fixation plates were performed by 3-D FE modelling [1].

Formerly, 3-D FE method was used to analyze the stress distribution patterns of non-anatomical but theoretically defined 3-D compact and spongious bone blocks around dental implant systems [1]. But, recently, anatomical models of dentate or edentate mandibles have been obtained with different modelling methods and various dental implant systems on distributions of stress and strain concentrations in the bone [1,2].

On the acceptability of these kinds of works done by the FE method, many factors have great importance. The anatomy and the material properties of the bone, the dimensions and the material properties of the implant system, the binding conditions of the bone-implant interface, detailed or coarse meshing of the model, and the boundary and the loading conditions of the model are major ones [1,2,3].

II. METHODOLOGY

1) *Modelling:* As a model, an edentate human cadaver mandible is selected. During this selection thoroughly filled tooth extraction sites, a moderately resorbed alveolar crestal bony structure on both sides are taken into consideration. Because of the thickness of the cortical layer in the mandible, computerized tomography (CT) is used in modelling. Totally 108 2-D coronal mandibular bone CT images perpendicular to alveolar processes and having a crosscut thickness of 1.5mm and a crosscut interval of 1mm are obtained from this edentate cadaver mandible in HiSpeed CT/i Imaging System (General Electric, Milwaukee, WI, USA) with known technical parameters. As printing CT images, the localization of the rulers aren't changed in order to serve as reference points whole through the modelling process. After CT images are transferred into the PC by using a special transparent scanner, totally 108 PC files are obtained (Fig. 1).

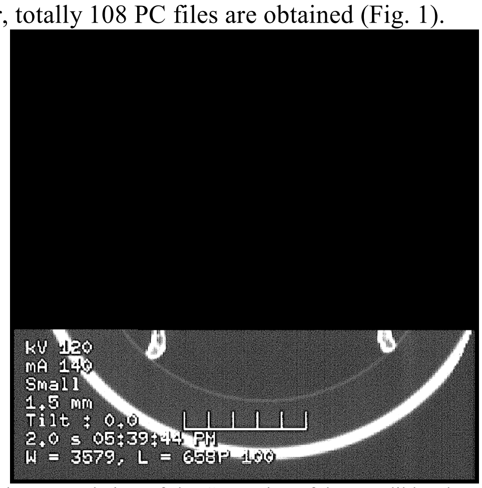

Fig. 1. The scanned view of the CT section of the mandible taken from the 73.5 mm.

The software that is used for modelling the three-dimensional mandible geometry necessitates vectorial data,

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Abstract

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instead of pixel data. For this necessity, each of the CT crosscut image of the mandible is replaced to the background in the Corel Draw 7.0 software package and lines are drawn through borders of both the cortical and spongious parts of the bone. Because of the almost perfect symmetry of the mandible with respect to the midsagittal plane, only the right half of the mandible is taken into consideration. The AutoCAD 13 software package is used for replacing the crosscut images one after the other in the 3-D geometric space. To form the volume of the model the SDRC I-DEAS Master Series 6A software package which also includes the FE analysis software is used. In this software consecutive areas are put together and the 3-D geometric model of the mandible consisting of two volumes, cortical and spongious parts, are obtained (Fig. 2).

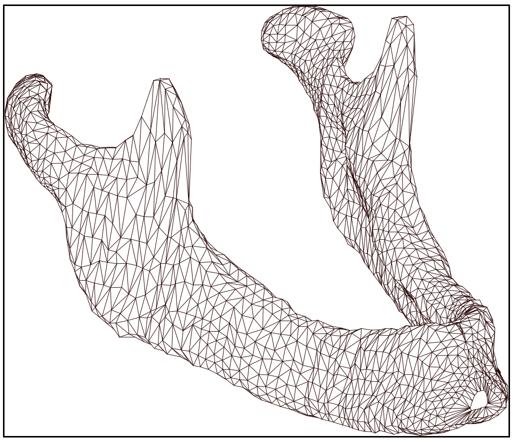


Fig. 2. The complete geometrical model of the mandible.

For the two implant supporting situation, by using the Denta-Scan software package CT examinations are performed on edentate human cadaver mandible with radiologic stents in order to ascertain the localization of implants on the model.

Dense trabecular structure of the compact and the sparse trabecular structure of the spongious parts are the characteristics of the mandible. The topography in the obliquecoronal crosssectional reformat images also corroborates this situation of the mandible.

2) *Material Properties:* Two different types of bone are distinguished, namely cortical bone and spongious bone, with different material properties. Cortical and spongious bones are assumed to be isotropic, homogeneous, and linearly elastic. Implant fixture and abutment models used in this study are added to geometric mandible model. In this work, a gold cylindrical abutment with a diameter of 4.5mm and a length of 6mm is modelled on to the hollow cylinder titanium implant fixture with a diameter of 3.5mm and a length of 16mm (Fig. 3). The material properties used in this work are presented in Table I.

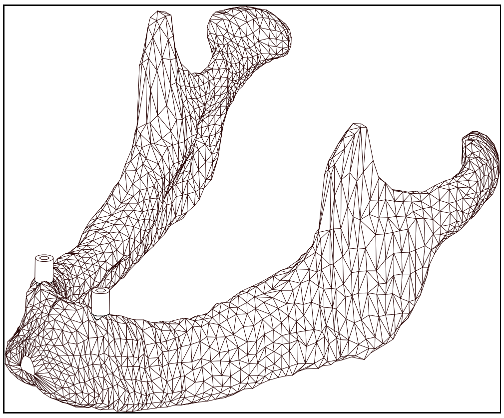
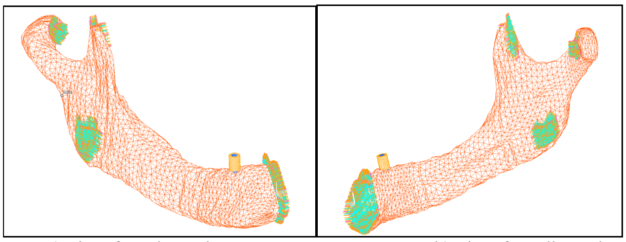


Fig. 3. Mandible model with two implants.

TABLE I
MATERIAL PROPERTIES USED IN THE FINITE ELEMENT MODE L

Materials	E (N/mm^2)	ν
Cortical bone	13.700	0.30
Spongious bone	1.370	0.30
Titanium (implant fixture)	103.400	0.35
Gold (abutment)	100.000	0.30

3) Boundary Conditions: During occlusion or biting on an object, the movement of the mandible with the implant system is prevented where the masticatory muscles and ligaments attach to the mandible. For this reason, in the FE model restraints to prevent displacement are placed at the nodes equivalent to those attachment areas (Fig. 4a and 4b).



a) view from buccal b) view from lingual

Fig. 4. Boundary regions of the model.

4) *Loading Conditions:* To simulate the clinical situation, points at the region of the attachment of the rele at th

$F_h : F_v : F_o = 1 : 3.5 : 7 \Rightarrow 14N : 50N : 100N$

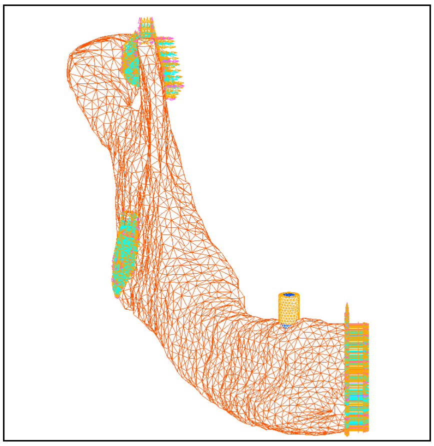


Fig. 5. Three loading conditions on the model.
a: Vertical bite force, b: Horizontal bite force, c: Oblique bite force.

A fixed bond between bone and implant along the whole interface is assumed. While dividing the volumes into elements, SOLID74, one of the standard 3-D elements of the I-DEAS software package, is used. Because of the almost perfect symmetry of the mandible with respect to the midsagittal plane, only the right half of the mandible is subdivided into elements. Also at the nodes in the symmetry plane, symmetry boundary conditions are prescribed (Fig. 5). The purpose of the study is primarily to calculate stresses in the bone adjacent to the implants, so a high accuracy is necessary in this region. For this reason, a fine mesh around the implants is generated. To save computer time and memory, the rest of the geometry is given a coarser mesh. The mesh generation resulted in 50682 elements (4-node tetrahedrons) and 11449 nodes in the bone around the implant, and 15737 elements (4-node tetrahedrons) and 4860 nodes in the remaining bone.

5) *Finite Element Analysis:* In the I-DEAS software package, after defining the geometry, elements, loading and boundary conditions, by the help of the SOLVE module, the mathematical analysis of the problem is carried out and the strain and stress results of every node are produced. The post-processing module in this software package is used to interpret the results in the form of stress strain concentration graphs.

III. Results and Discussion

Strain and stress concentration results of three bite forces in the bone around the dental implant are found to be located in the neck of the implant. In general, the resorption areas around dental implants are found to be in the same locations. In Fig. 6 and Fig. 7, the topography yUMJw]QMa m u = q qY Q c M Q T U V O M N = M = q qM K stress, and presentation of the understandable numerical result values [1].

As compared with the 2-D model, a 3-D model can give more details about the stress or strain concentrations in the bone around implants. Although the clinical situation is approached more closely by the geometry and the loading of the model than the 2-D model, assumptions about the mechanical behavior of the bone and about the bone-implant interface condition make the calculated displacements and stresses still an approximation to the actual ones. From this point of view, a 3-D model is formed and a 3-D FE method is used. Recently used 3-D anatomical mandible models for the stress analysis around dental implants support the clinical importance of our study [1,2].

In many similar studies done with the same analysis method, digitizers, histological bone crossections with 2-5mm intervals parallel to the frontal plane [2], non-anatomical mandible model, and transaxial CT images taken with 1mm intervals are used in modelling. In our work, coronal CT method with 1mm intervals is prefered for the detailed view of the bone structure [1].

As in many of the similar studies [2], in our work while modelling the bone-implant interface a fixed bond is assumed and then results are obtained. Quantitative results from this FE analysis can not be compared with other studies in the literature, because of differences in geometry and boundary conditions. Comparing qualitative results from 3-D FE studies reveal that if a fixed bond between implant and bone is assumed, the extreme principal stresses are found in the crestal region around the neck of the implant.

V. Conclusion and Future Work

It is proved that the localizations of the extreme principal stress concentrations obtained after FE analysis are similar to the localizations of the bone resorption areas occurred in two implants supported mandibular prostheses in clinics. The greatest advantage of this kind of work is that to some degree without applying an implant supported prosthesis to a patient, both the specialist and the patient can see the final results. For this reason, the model presented in this paper can be used for the development of new CAD tools, which can be preferred in treatment planning of implant prostheses in dental clinics.

References

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